

## Biometric relationships of the red shrimp, *Aristaeomorpha foliacea* Risso 1827, in the Strait of Sicily (Mediterranean Sea)\*

SERGIO RAGONESE<sup>1</sup>, FRANCESCO BERTOLINO<sup>1</sup> and MARCO L. BIANCHINI<sup>2</sup>

<sup>1</sup>Ist. Tecnologia Pesca e Pescato, CNR, via Vaccara 61, 91026 Mazara (TP), Italy.  
<sup>2</sup>P.F. "RAISA", CNR, via Tiburtina 770, 00159 Roma, Italy.

**SUMMARY:** The biometric relationships between different body measures (in length) and body weight of the giant red shrimp, *Aristaeomorpha foliacea*, from the Strait of Sicily (Central Mediterranean Sea) were analysed. A maximum likelihood index of goodness of fitting (Furnival's index) was used to compare the performance of the models. Fresh and thawed measures were also compared, the latter being significantly different from the former. Total and ocular length and length-weight relationships resulted significantly negative allometric ( $b < 1$  or  $b < 3$ , respectively) in both sexes. Length relationships in males showed discontinuities as a consequence of their rostrum shortening process. The estimated coefficients in the morphometric relationship for females were used to compare standard (based on carapace length) and other (based on different body measures) length frequency distributions derived from older literature. The length-weight relationship for *A. foliacea* females of the Strait of Sicily appeared very similar to those derived for other conspecific populations, but quite different (higher weight for the same length) in respect to the similar species *Aristeus antennatus*.

**Key words:** Biometry, red shrimp, *Aristaeomorpha foliacea*, Mediterranean Sea.

**RESUMEN:** RELACIONES BIOMÉTRICAS DE LA GAMBA ROJA (*ARISTAEOMORPHA FOLIACEA* RISSO, 1827) EN EL ESTRECHO DE SICILIA (MAR MEDITERRÁNEO). – Las relaciones biométricas entre diferentes medidas del cuerpo (largo) y peso corpóreo de la gamba roja, *Aristaeomorpha foliacea*, del Estrecho de Sicilia (Mar Mediterráneo Central) fueron analizadas. Para comparar el desempeño de los modelos se aplicó un índice de máxima verosimilitud de acierto de medición, el índice de Furnival. También se compararon las medidas de ejemplares frescos y descongelados, resultando las primas sumamente diferentes de las segundas. El largo total y ocular, así como las relaciones largo/peso, dieron un resultado alométrico muy negativo ( $b < 1$  o  $b < 3$  respectivamente) en ambos sexos. Las relaciones de longitud en los machos mostraron falta de continuidad como consecuencia del proceso de acortamiento del rostrum. Los coeficientes estimados en la relación morfométrica para las hembras fueron empleados para comparar datos estándar (basados en la longitud de la carapaz) y otros datos (basados en varias medidas corpóreas) relativos a la distribución por frecuencia de longitudes tomados de literatura más antigua. La relación tamaño/peso de las hembras *A. foliacea* del Estrecho de Sicilia parece ser muy semejante a la relación establecida para otras poblaciones coespecíficas, aun siendo bastante distinta (peso más elevado para el mismo tamaño en longitud) respecto a especie semejante *Aristeus antennatus*.

**Palabras clave:** Biometría, gamba roja, *Aristaeomorpha foliacea*, Mar Mediterráneo.

\*Received September 3, 1996. Accepted April 7, 1997.

## INTRODUCTION

The giant red shrimp, *Aristaeomorpha foliacea* (Risso, 1827), belongs to the family Aristeidae, which includes other important species such as the blue and red (*Aristeus antennatus* Risso, 1816) and the scarlet shrimps (*Plesiopenaeus edwardsianus* Johnson, 1868) (Holthuis, 1987).

*A. foliacea* occurs in Mediterranean, Central Atlantic, South Africa and in the IndoPacific ocean, showing a preference for muddy bottoms, with aggregations mainly in submarine trenches and canyons along the continental slope from 150 m to 1850 m with a peak in abundance between 300 m and 700 m (Grey *et al.*, 1983; Holthuis, 1987; Dietrich, 1987; Pérez Farfante, 1988; Bianchini and Ragonese, 1994). *A. foliacea* and *A. antennatus* are often caught together in the Strait of Sicily (Central Mediterranean Sea; Fig. 1), but the giant red shrimp outnumbers here the blue-and-red shrimp (Ragonese, 1995), whereas the opposite happens in the Western Mediterranean (Sardà, 1988; Bianchini and Ragonese, 1994).

Since the giant red shrimp is a valuable species for local and offshore fleets which trawl the mesobathyal level (>350-400 m) of the Strait of Sicily, where landing are estimated to be above 1000 tons per year and worth about 15 million \$ US, there is a growing interest on this resource, resulting in increased knowledge about its distribution, biology and life history (Ragonese *et al.*, 1994; Ragonese and Bianchini, 1995); nevertheless, only scanty data exists on the morphometric relationships of this population.

In the past, body measures other than the carapace length were used, e.g., "total body length" (Azouz, 1972), "ocular length" (Arena and Li Greci, 1973) and "curvilinear total length" (Balestra *et al.*, 1975). The relationships between the carapace length vs. total and ocular length and body weight have been therefore analyzed in order to allow comparisons with other populations and make data collected by older authors comparable with today standard measures.

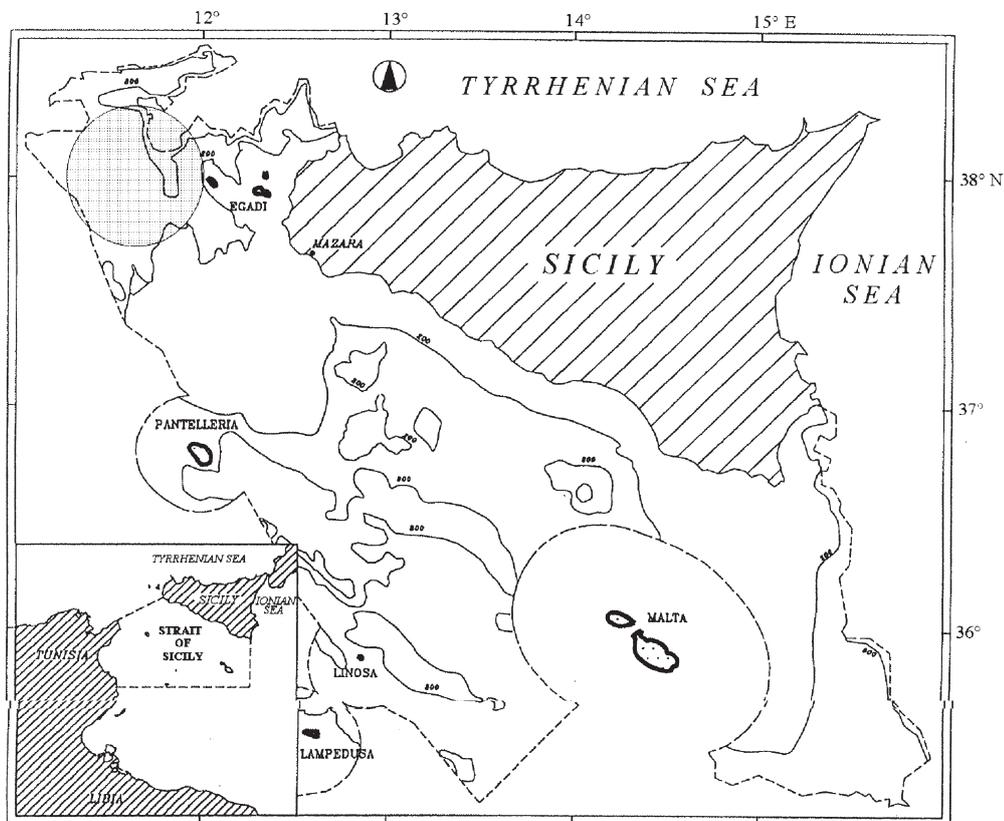


FIG. 1. – The Strait of Sicily, with evidenced the area of the length frequency comparison (historical vs. present data, see fig. 5).

## MATERIAL AND METHODS

Morphometric relationships are based on fresh shrimps samples collected in the Strait of Sicily during Spring and Summer 1989 by short-range commercial trawlers belonging to the fleet of Mazara del Vallo. In fact, the “fresh” shrimps catch of the short-range trawlers includes the whole size interval (practically no discards), sorted in four categories: small (juveniles, often mixed with other species like *Parapenaeus longirostris*), 3rd (small specimens, mainly males), 2nd (large males and small/medium females) and 1st (large females). The shrimps are deepsoaked in a solution of sodium metabisulphite in order to prevent the “black” spot, then boxed (about 8 kg/box) and stored in a cool place, usually without ice, and landed after a few hours.

Multiple sub-samples were collected until the whole size range (20-40 mm and 20-70 mm, carapace length, for males and females respectively) was represented. In the laboratory, the specimens were soaked in tap water, sorted by sex, measured (Fig. 2) and weighed. Water was drained from the surface and the gill-chambers by allowing the samples to rest upon a plastic sieve.

The “oblique” carapace length (hereafter CL), from the posterior margin of the orbit to the posterior or hind edge of the carapace, was considered the standard measure (Farmer, 1986; Dall *et al.*, 1990). CL was recorded with a dial caliper, to the millimeter below; to “balance” the sample, an upper limit of 10-15 specimens for each length class (1 mm) and sex was set (i.e., a length-stratified sample). Each specimen was placed on its back over a flat metallic ichthyometer and gently stretched; the “total length” (hereafter TL), from the tip of the rostrum to the edge of the telson, and the “body length”, according to Farmer (1986), hereby defined as “ocular length” (OL), from the posterior margin of the orbit to the tip of the telson, were measured. Total body weight (BW) was recorded (at 0.1 g) using an analytical balance. Only specimens without damage in any part of the body were considered; in case of damage to the tip of the rostrum the specimen was maintained, except for TL-CL analysis.

Specimens were then placed individually in a plastic bag, labelled, deep-frozen (-30°C) overnight, and stored at -18°C for two weeks (the usual period of both experimental surveys and commercial offshore trawl operations). The shrimps were then defrosted (overnight at room temperature) and mea-

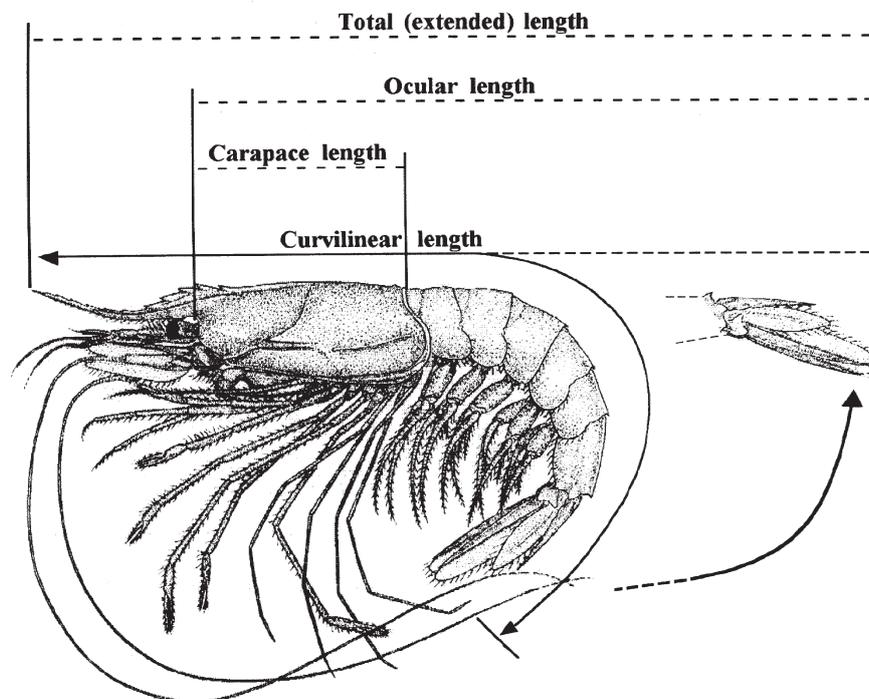


FIG. 2. – Measurements taken on red shrimps, as reported in the literature.

sured again. Thawed vs. fresh measures were compared using both parametric (“paired t”) and non-parametric (“sign” for lengths and “Wilcoxon” for weights) tests, in order to detect any difference between fresh and thawed conditions; thereafter, only the fresh measures were used for further investigations.

A total of 635 specimens, 394 females and 241 males, were included in the sample. Descriptive statistics for both fresh and thawed specimens are reported in Table 1. Total length (TL) is the most critical measure since many shrimps had damaged rostrum: in the fresh samples, the number with missing TL was 46 over 394 (11.7%) and 26 over 241 (10.8%), in females and males respectively.

The carapace length vs. total length or ocular length relationships were investigated, since a simple linear regression resulted unsuited, using a linearized allometric (natural logs) model:

$$\log Y = a + b * \log X + \epsilon$$

where X is the independent variable, Y is the dependent variable, representing the measurements of body parts; a and b are constants;  $\epsilon$  is a normally distributed random variable.

The same model was used for the length-weight relationships.

Least square estimates of parameters were based on the predictive or Type I linear regression model (Sokal and Rohlf, 1981). The t test (ratio of the difference from the expected value and relative standard error of the coefficient) was used to test the hypothesis of isometry ( $b=1$  or  $b=3$ , for length and weight relationships respectively). The occurrence of discontinuities (disharmonies or splines) in the relationship was examined using a piece-wise linear regression model (Neter *et al.*, 1985, modified by Wilkinson, 1987).

The standard assumptions of the regression models (the so-called Gauss-Markov’s conditions, i.e., independence and normality/lognormality of residuals, homogeneity of variance, etc.) were evaluated using scatterplots of variables, Studentized residuals vs. estimates, normality plot of residuals, and by performing a Kolmogorov-Smirnov test on standardized (Studentized) residuals (Lilliefors test; in Wilkinson, 1987). A “runs test” was used to check the lack of randomness in residuals, i.e., the absence of pattern (Draper and Smith, 1981). Rejection levels were defined as statistically significant ( $0.01 < P < 0.05$ ) or highly significant ( $P < 0.01$ ).

TABLE 1. – Descriptive statistics of the samples of females and males of *Aristaeomorpha foliacea* used in the analyses (N.B.: means are not representative of the population).

|                       |      | Carapace length (mm) |        |           | Total length (mm) |        |           | Ocular length (mm) |        |           | Body weight (g) |        |           |
|-----------------------|------|----------------------|--------|-----------|-------------------|--------|-----------|--------------------|--------|-----------|-----------------|--------|-----------|
|                       |      | fresh                | thawed | log-fresh | fresh             | thawed | log-fresh | fresh              | thawed | log-fresh | fresh           | thawed | log-fresh |
| F<br>E<br>M           | N    | 394                  | 394    | 394       | 349               | 338    | 349       | 393                | 385    | 393       | 394             | 390    | 394       |
|                       | min  | 20                   | 19     | 2.996     | 95                | 99     | 4.554     | 74                 | 74     | 4.304     | 3.2             | 2.6    | 1.163     |
|                       | max  | 65                   | 65     | 4.174     | 259               | 254    | 5.557     | 205                | 199    | 5.323     | 79.0            | 74.4   | 4.369     |
|                       | mean | 37.9                 | 37.8   | 3.589     | 164.2             | 165.3  | 5.075     | 129.8              | 129.9  | 4.833     | 22.8            | 21.5   | 2.834     |
|                       | s.d  | 11.19                | 11.20  | 0.310     | 36.82             | 35.70  | 0.232     | 32.44              | 31.42  | 0.260     | 16.39           | 15.36  | 0.822     |
|                       |      | Carapace length (mm) |        |           | Total length (mm) |        |           | Ocular length (mm) |        |           | Body weight (g) |        |           |
|                       |      | fresh                | thawed | log-fresh | fresh             | thawed | log-fresh | fresh              | thawed | log-fresh | fresh           | thawed | log-fresh |
| M<br>A<br>L<br>E<br>S | N    | 241                  | 241    | 241       | 215               | 209    | 215       | 241                | 236    | 241       | 241             | 241    | 241       |
|                       | min  | 20                   | 20     | 2.996     | 97                | 95     | 4.575     | 72                 | 73     | 4.277     | 3.1             | 2.5    | 1.131     |
|                       | max  | 43                   | 43     | 3.761     | 174               | 169    | 5.59      | 160                | 155    | 5.075     | 28.6            | 26.8   | 3.353     |
|                       | mean | 29.9                 | 29.8   | 3.377     | 132.9             | 132.4  | 4.883     | 111.2              | 111.2  | 4.692     | 12.2            | 11.5   | 2.333     |
|                       | s.d. | 6.06                 | 6.02   | 0.210     | 15.65             | 15.73  | 0.120     | 21.45              | 21.46  | 0.198     | 6.50            | 6.36   | 0.606     |

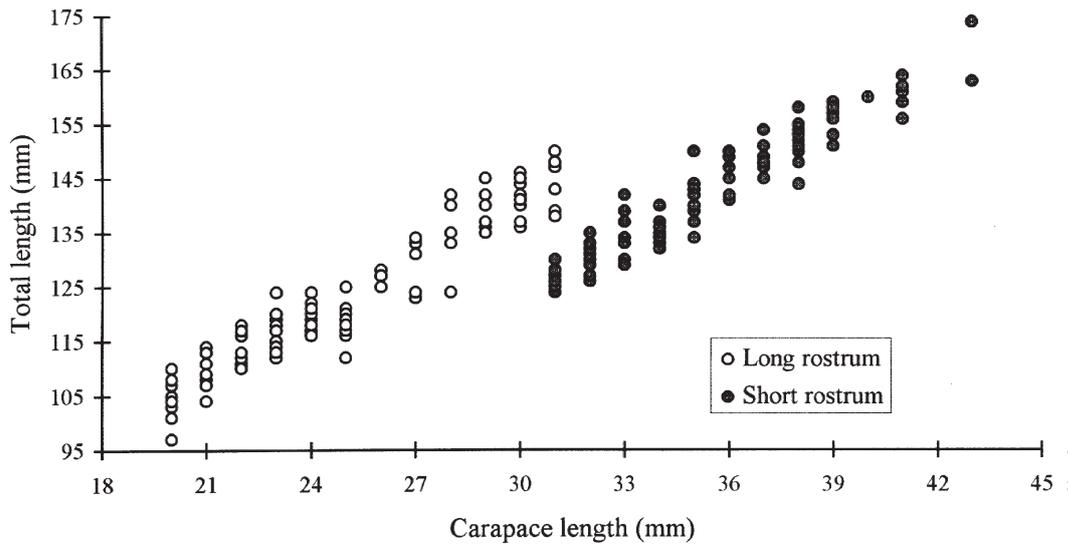


FIG. 3. – Total length vs. carapace length in males of *Aristaemomorpha foliaceae*.

The presence of influential observations was detected by analyzing the Cook's statistic (Neter *et al.*, 1985). Observations with extreme Cook's values were momentarily removed, the new estimates computed and compared with the previous ones; as a

rule of thumb, in the case of non-substantial difference between the standard errors of estimates, the suspected observations were maintained. The coefficient of determination ( $r^2$ ) was used as index of the strength of the linear association. The Furnival's

TABLE 2. – Summary of the regressions for females and males (long and short-rostrated). Legenda: N: sample size; a: first parameter in the allometric model; b: slope coefficient of the model; s.e.: standard error of the corresponding coefficients;  $r^2$ : coefficient of determination; I: Furnival's index of fit; Residuals N-test and R-test: shape of the normal and the residuals plots; Cook's values: number of suspected elements and number of outliers (with comparison values).

|                            | N             | a      | s.e.(a) | b     | s.e.(b) | $r^2$ | I     | Residuals<br>normality | randomn    | suspect | Cook's value<br>high |                 |
|----------------------------|---------------|--------|---------|-------|---------|-------|-------|------------------------|------------|---------|----------------------|-----------------|
| Total vs. Carapace length  |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| F                          | 349           | 2.376  | 0.022   | 0.755 | 0.006   | 0.978 | 5.4   | departure              | no trend   | 3       | 0                    |                 |
| Ocular vs. Carapace length |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| M                          | 392           | 1.839  | 0.013   | 0.834 | 0.003   | 0.992 | 2.9   | departure              | no trend   | 3       | 0                    |                 |
| Weight vs. Carapace length |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| A                          | 394           | -6.647 | 0.043   | 2.642 | 0.012   | 0.992 | 1.2   | ok                     | no trend   | 0       | 0                    |                 |
| Total vs. Carapace length  |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| M                          | long-rostrum  | 104    | 2.500   | 0.071 | 0.719   | 0.022 | 0.912 | 3.9                    | ok         | bad     | 3                    | 1(0.8 vs. <0.4) |
|                            | short-rostrum | 111    | 1.786   | 0.102 | 0.890   | 0.029 | 0.898 | 3.4                    | ok         | bad     | 3                    | 1(0.8 vs. <0.4) |
| Ocular vs. Carapace length |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| L                          | 241           | 1.525  | 0.026   | 0.938 | 0.008   | 0.984 | 2.7   | ok                     | 2 clusters | 2       | 0                    |                 |
| Weight vs. Carapace length |               |        |         |       |         |       |       |                        |            |         |                      |                 |
| S                          | 241           | -7.368 | 0.065   | 2.873 | 0.019   | 0.989 | 0.6   | ok                     | no trend   | 0       | 0                    |                 |

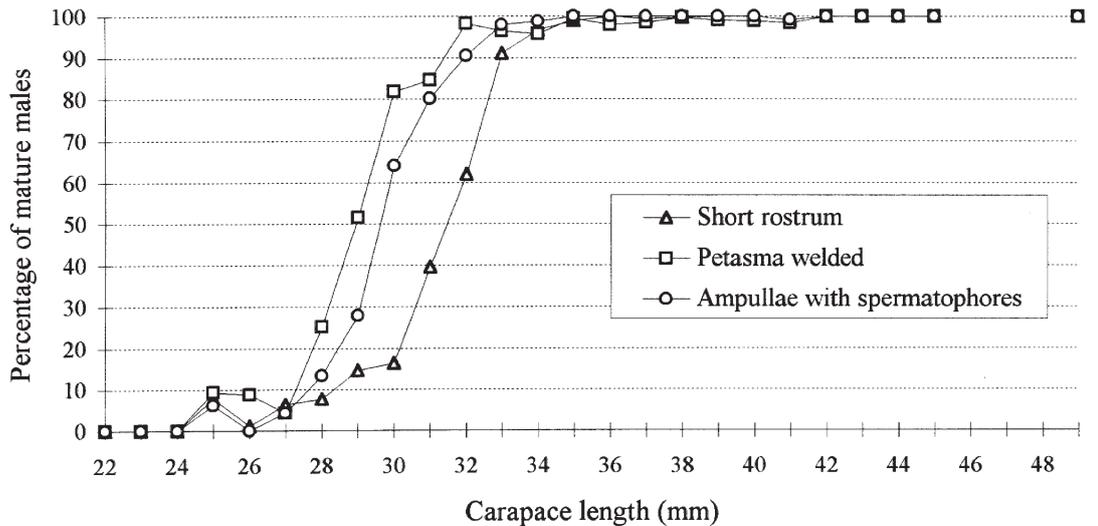


FIG. 4. – Evolution with size of the percentage of mature males of *Aristaemomorpha foliaceae* according to three different criteria.

index (Furnival, 1961) was used to compare the goodness of fit among other models. The Furnival's index (herein denoted as I) is a modified maximum likelihood estimator useful for comparing the fit of equations after transformation of the original variables; in this case:

$$I = [\exp(\text{mean } \log Y_i)] * \text{SEE}$$

where SEE denotes the standard error of the estimate (i.e., the square root of the mean square error); of course, the lower the index the better the model fit.

After having chosen the model, the historical available measures different from the standard carapace length were converted by inverse prediction and the length frequency distributions compared; data coming from fishing grounds at SW Egadi (Fig. 1) were examined in detail. Estimated morphometric coefficients were also qualitatively compared with the estimates available from other conspecific populations.

Least squares estimates (AM or type I regression) were preferred to the standard major axis estimates (GM) as a consequence of the predictive finality of the present work (Jolicoeur, 1975; Sprent and Dolby, 1980; Sardà *et al.*, 1995). Thorough considerations about these aspects can be found in Hartnoll (1982), Lovett and Felder (1989) and Ebert and Russell (1994), however AM estimates may be converted in GM estimates (Ricker, 1973), given the mean values of both dependent and independent

variables and the AM coefficient of correlation, according to the following formulations:

$$a' = \text{mean}(Y_i) [b' * \text{mean}(X_i)] - \text{and } b' = b/r$$

where  $a'$  and  $b'$  denote the GM intercept and slope, respectively.

## RESULTS

Thawed measurements (Table 1) for all the variables considered (CL, TL, OL and BW) are systematically lower than the fresh ones in both sexes, and the differences result to be highly significant according to the t-test and the nonparametric tests. With respect to linear measures, total and ocular lengths were more affected than carapace length by the defrosting process (absolute t-values of 5.0-9.6 vs. 4.2-5.3), whereas for the body weight the t-statistic went up to 18-27 (absolute values). Nonparametric tests lead to the same conclusion, supporting their parametric counterparts. Considering the regression approach (thawed =  $b$ \*fresh), the average length decrement was however quite low (ca. 1%) whereas the average loss in body weight resulted of about 5%.

Results of the morphometric analyses, divided by sex, are reported in Table 2, which shows the output of the regressions, as well some of the elements useful to interpret the goodness of the estimates: coefficients of determination, Furnival's index of fit (I), screening

of the residuals plots, test of normality, number of suspected values and extreme Cook's statistics. In all analyses, removal of data of extreme Cook's values never significantly improved the results: therefore, the data sets were always kept at their original size.

As a general rule, the situation for the females is quite straightforward, with a unique, continuous regression line, since juveniles and adults do not show any abrupt change in their morphology; the residual plots do not show evident trends, but the departure from normality of the data distributions is sometimes bothersome, even if the tests used are deemed robust.

The regression of TL vs. CL after logarithmic transformation indicates a significant negative allometry ( $b < 1$ ); incidentally, the attempt to fit a piecewise line was unsuccessful. The log-linear regression of OL vs. CL shows a significant negative allometry ( $b < 1$ ), but less than that observed in the TL-CL relationship.

Speaking of BW vs. CL, a change in slope seems to occur above the 45-50 mm CL sizes, but attempts to fit a piece-wise regression were unsuccessful. Results indicate log-linearity, a significant negative allometry ( $b < 3$ ) and a strong improvement in Furnival's index in respect to both the length-length relationships.

The morphometric analysis of males is more complex, since there is an evident discontinuity in their body measurements as a consequence of the dimorphism of the rostrum in juveniles and adults (Fig. 3); the residuals do not behave well and show clustering patterns; all sets of data can be considered normally distributed.

In the relationship TL vs. CL, particularly evident is the "jump" which defines two well-separated sets of point at CL= 31 mm: long-rostrated specimens above (mean TL= 143.4 mm, sd= 4.92, range= 138-150 mm, n= 7) and short-rostrated specimens below (mean TL= 126.7 mm, sd= 2.16, range= 124-128 mm, n= 6). Consequently, at least two different curves characterize this relationship, and data must be treated as such; other discontinuities, apparent in the scatterplot, were not confirmed by the statistical analysis. After log-linear transformation, a strong negative allometry characterise both groups but it is worth noting that the slope of short-rostrated males is lower than that of longrostrated males. Practically, only a small difference results in the index of goodness of fit ( $I = 3.37$  vs.  $I = 3.93$ ) between the two groups, short-and long-rostrated.

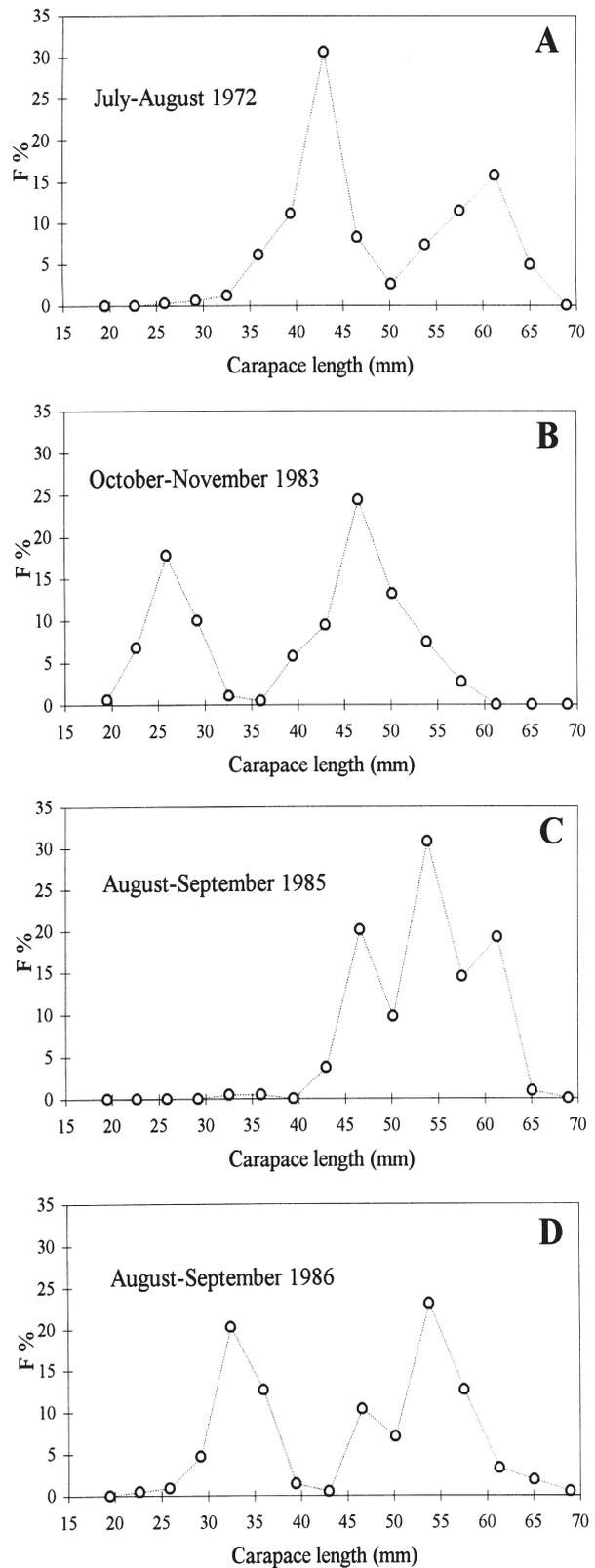


Fig. 5. – Comparison between *Aristaemomorpha foliaceae* females length frequency (%) distribution from the same area (shaded in fig. 1) but different periods. Source: A: Arena and Li Greci, 1973; B: Arena, 1985; C and D: Ragonese, 1995.

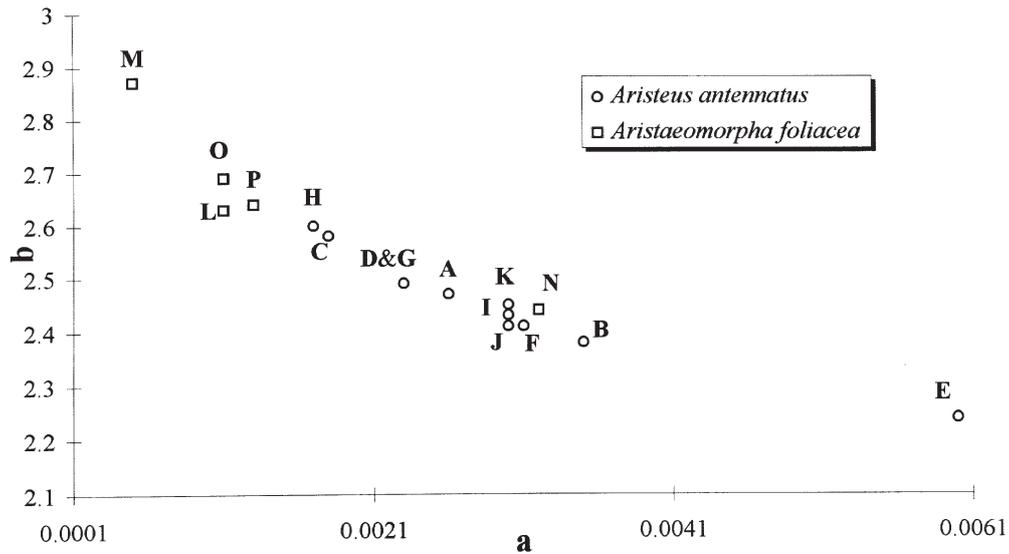


FIG. 6. – Qualitative comparison of the different weight-carapace length relationships in red shrimps: a and b denote the coefficients ( $W = a \text{ CL}^b$ ); see Table 3 for the letter codes.

Speaking of the relationship of OL vs. CL, also for these variables the scatterplot indicates a complex relationship; two breakpoints are appreciable at 25-26 mm CL and 31-32 mm CL, respectively. Consequently, three clusters of points (1st: CL <27 mm and OL <100 mm; 2nd: CL <31 mm and OL >100 mm; and 3rd: CL >31 mm and OL >100 mm) were subjectively identified and the fit of three lines was attempted. However, the separate estimation does

not improve the estimates derived by the whole set of data, where a slight but still significant negative allometry condition (0.94) is present.

A spline is again apparent at CL <27 mm for the BW vs. CL. The strength of the association is very high; the relationship is negatively allometric, and the slope is higher than that estimated for females (i.e., for the same length class males weigh more than females).

TABLE 3. – Weight-length relationships for females of *Aristaeomorpha foliacea* (Af) and *Aristeus antennatus* (Aa) in different areas; model: ( $W = a \text{ CL}^b$ ).

| Species | a      | b    | Area                     | Authority                                                      | Code |
|---------|--------|------|--------------------------|----------------------------------------------------------------|------|
| Aa      | 0.0026 | 2.47 | Catalan Sea              | Demestre 1990                                                  | A    |
| Aa      | 0.0035 | 2.38 | Valencia                 | Lleonart 1990                                                  | B    |
| Aa      | 0.0018 | 2.58 | Murcia                   | Martínez Baños <i>et al.</i> 1988                              | C    |
| Aa      | 0.0023 | 2.49 | Portugal                 | Ribeiro Cascalho and Arrobas 1982                              | D    |
| Aa      | 0.0060 | 2.24 | Central Tyrrh. Spr+Sum   | Ardizzone <i>et al.</i> , in AA.VV. 1988                       | E    |
| Aa      | 0.0031 | 2.41 | Central Tyrrhenian       | Minervini <i>et al.</i> , in AA.VV. 1988                       | F    |
| Aa      | 0.0023 | 2.49 | Southern Portugal        | Santos and Cascalho, in Bianchini and Ragonese (eds) 1994      | G    |
| Aa      | 0.0017 | 2.60 | SE Spain (Murcia)        | Martínez Baños and Mas, in Bianchini and Ragonese (eds) 1994   | H    |
| Aa      | 0.0030 | 2.43 | SE Spain (Ibiza)         | Martínez Baños and Mas, in Bianchini and Ragonese (eds) 1994   | I    |
| Aa      | 0.0030 | 2.41 | Majorca                  | Carbonell, in Bianchini and Ragonese (eds) 1994                | J    |
| Aa      | 0.0030 | 2.45 | Northern Tyrrhenian      | Righini and Abella, in Bianchini and Ragonese (eds) 1994       | K    |
| Af      | 0.0011 | 2.63 | Central Tyrrh. Spr+Sum   | Ardizzone <i>et al.</i> , in AA.VV. 1988                       | L    |
| Af      | 0.0005 | 2.87 | Central Tyrrhenian       | Minervini <i>et al.</i> , in AA.VV. 1988                       | M    |
| Af      | 0.0032 | 2.44 | Northern Tyrrhenian      | Righini, P. and A. Abella. 1994                                | N    |
| Af      | 0.0011 | 2.69 | South Tyrrh. Aut+Spr+Sum | Spedicato <i>et al.</i> , in Bianchini and Ragonese (eds) 1994 | O    |
| Af      | 0.0013 | 2.64 | Strait of Sicily         | Ragonese <i>et al.</i> (this note)                             | P    |

## DISCUSSION

Morphometric analysis and relative growth studies (where postmolt vs. premolt is a special case) are widely used, especially for heavily armoured crustaceans, such as lobsters and crabs, because of their hard integument and possibility of abrupt changes during the ontogenesis. The goals of this study included searching for splines, not only in the ontogenetic development (for instance, the “puberty molt”), but also for changes in the relationships likely related to variations in growth rates (Somerton, 1980; Hartnoll, 1982), and for sex-specific allometry related to sexual dimorphism (Hartnoll, 1982; Lovett and Felder, 1989).

In *A. foliacea*, however, like in the companion species *A. antennatus*, growth occurs almost continuously because the exoskeleton is more flexible and molting is frequent (diecdysis molting cycle; Dall *et al.*, 1990). Furthermore, maturity processes are more gradual and sexual maturity, mating and spawning occur over a large size-age range. No terminal molt is known for this species (Hartnoll, 1985; Sardà and Demestre, 1987; Ragonese *et al.*, 1994; Ragonese and Bianchini, 1995). The above features can explain why, despite some apparent discontinuities in the scatterplots, no disharmony has been statistically detected for females *A. foliacea* (present study) and *A. antennatus* (Sardà *et al.*, 1995).

A quite different picture regards males of *Aristeids* which reach a smaller size in respect to females and undergo an abrupt change in the rostrum length a short rostrum representing the most apparent macroscopic morphometric feature of male adulthood, although the shortening process is not directly related to maturation, at least in *A. antennatus* (Sardà and Cartes, 1994), and about whose ecological role different hypotheses have been proposed (Pérez Farfante, 1987; Sardà and Demestre, 1989). The TL-CL plot of males of *A. foliacea* derived in this study (Fig. 3) suggests another discontinuity in the range 25-28 mm CL, perhaps reflecting some less apparent maturity processes such as storage of spermatophores in the terminal *ampullae* and the welding of the copulatory organ, the petasma (Holthuis, 1987), all of which are considered as indexes of sexual maturity in *Aristeid* males (Relini Orsi and Relini, 1979; Sardà and Demestre, 1987, 1989). To evaluate this hypothesis, the pattern of the above processes with increasing size (CL) was derived from an original data-base collected over four seasons (Spring '86; Summer '86; Autumn '86 and Winter '87) from

trawl surveys carried on in the Strait of Sicily (Ragonese *et al.*, 1994). Seasons were combined and the percentage of males with short-rostrum, males with welded-petasma and males with spermatophore pads in the *ampullae* were plotted against carapace length (Fig. 4). The graph indicates that the shortening of the rostrum follows the storage of spermatophores and the welding of petasma. For the rostrum, the change from long to short condition occurs between 29 and 33 mm CL (primarily in 31-32 mm range); for the petasma and *ampullae* characters, the transition is more gradual. Above 33-35 mm CL, all males are apparently “fully mature”. Consequently, the presence of disharmonies in males other than the macroscopic jump at 31 mm CL might be expected; still, present data did not allow a statistical confirmation. One explanation could lie in a slight discrepancy (or high variability) in the maturation processes among different cohorts of males; in fact, trawl data suggest three gradual and overlapping patterns in the relationships between proportions of males with *ampulla seminalis* filled with spermatophores, with welded petasma and with short rostrum. As a matter of fact, the rostrum shortening in *Aristeids* is described as drastic (Cau *et al.*, 1982), or as gradual but marked both with seasonality and coexistence of three different (long, short and intermediate) types (Sardà and Demestre, 1989), or as a gradual but slow and continuous process (Perez Farfante, 1987). For the above considerations, present results for males have to be considered inconclusive for predicting total length and ocular length from carapace length, whilst the estimates concerning the length-weight relationship should be used with caution.

Speaking of data gathering, it appears that measures taken on defrosted specimens are systematically and significantly lower than those taken on fresh samples; however, the differences are so small in absolute values as to be almost influential in further data processing.

As concerns the aptness of the models used, two considerations can be drawn for females: first, the presence of “influential” observations has not compromised the results, likely a consequence of the good sample size; and, second, the weakest hypothesis resulted the normality of residuals but, luckily, least squares techniques are quite robust in respect to this violation. As concerns the use of a linear or a log-linear model, the two approaches yield practically the same goodness of fit: on one end, this should support the widespread use of the simple linear model in shrimps morphometric studies (Farmer,

1986; Lovett and Felder, 1989; Dall *et al.*, 1990); on the other end, however, the log-linear model has been preferred in this study because it is more sound from a biological point of view and because the risks of finding local minima and the difficulties encountered in trying to fit a piece-wise regression were considered.

The weight-carapace length regressions show a statistically significant negative allometry in females, more pronounced than that observed in males. One implication of this result lies in the violation of the isometric assumption which is central to many models that incorporate growth, such as the yield-per-recruit model of Beverton and Holt, where carapace length is used as an index of size.

Log-linear coefficients from Table 2 allowed the conversion of historical nonstandard (TL; OL) measures in standard (CL) length frequency distributions comparable with recent data (Fig. 5); strong variation in the strength of the class of the recruits appears to be the most streaking feature, whereas the consistency of largest females seems to be more or less comparable despite 20 years of exploitation. As a matter of fact, the highly irregular grounds of this area, where only few obliged-track hauls can be made, allow a natural protection against overfishing, contrarily to other areas in the Strait of Sicily where a decrease in catch per unit of effort has been evidenced.

Another goal of such studies consists in the possibility of comparison with other available morphometric relationships; unfortunately, very scanty data exist for *A. foliacea* and only length-weight relationships can be reasonably compared. These data are presented in Table 3, together with estimates derived for the companion species *A. antennatus*. Coefficients estimated in this study are strictly comparable with the conspecific estimates with the only exception of the population off the Tuscanian coasts (code N in Table 3 and Fig. 6). It is worth noticing that estimates indicate that females of *A. foliacea* weigh more than females of *A. antennatus* of the same carapace length, with the above-mentioned exception.

#### ACKNOWLEDGMENTS

Authors are indebted with Francisco Sardà and Margarida Castro for their valuable comments and suggestions, and with Ugo Morara for the help in preparing the manuscript.

#### REFERENCES

- Ardizzone, G.D., A. Belluscio, R. Coen, F. Gravina, R. Maj, F. Scaletta, P. Schintu and A. Somaschini. – 1988. Relazione sulle campagne di pesca svolte dall'Unità. Operativa n. 6 (zona Torvaianica Foce Garigliano) nell'ambito del progetto *Risorse demersali* (finanziamento Ministero Marina Mercantile) durante il triennio 1985-1987. *Min. Marina Mercantile, Dir. Gen. Pesca Marittima (mimeo)*: 32 pp.
- Arena, P. – 1985. *Studio sulla possibilità di razionalizzare e rendere più produttiva la pesca a strascico nel Canale di Sicilia e nel Mediterraneo centro-meridionale*. E.S.P.I.: 33 pp.
- Arena, P. and F. Li Greci. – 1973. Indagine sulle condizioni faunistiche e sui rendimenti di pesca dei fondali batiali della Sicilia occidentale e della bordura settentrionale dei banchi della soglia siculo-tunisina. *Quad. Lab. Tecnol. Pesca*, 1: 209 pp.
- Azouz, A. – 1972. Les crustacés comestibles (crevettes et langoustines) des mers tunisiennes. *Bull. Inst. Oceanogr. Pêche, Salammbô*, 2: 275-301.
- Balestra, V., M.L. Bianchini, R. Cattaneo and S. Re. – 1975. Studio ed osservazioni biometrico-statistiche sull'accrescimento relativo di alcuni crostacei batiali; nota II: *Aristeomorpha foliacea* (Risso). *Pubbl. Ist. Talassogr. F. Vercelli*, 520: 1-15.
- Bianchini, M.L. and S. Ragonese (eds). – 1994. Life cycles and fisheries of the deep water shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus*. Proc. International Workshop held in the Istituto Tecnologia Pesca e Pescaio, Mazara (Italy), 28-30 April 1994. *N.T.R.-I.T.P.P. Special Publ.*, 3: 88 pp.
- Carbonell, A. – 1994. Life cycle of *Aristeus antennatus* on Majorca Island waters. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaeomorpha foliacea and Aristeus antennatus*. *N.T.R.-I.T.P.P. Special Publ.*, 3: 13-14.
- Cau, A., A.M. Deiana and M. Mura. – 1982. Nuovi dati sull'accrescimento e sulla maturità sessuale di *Aristaeomorpha foliacea* (Risso, 1827) (Decapoda Penaeidae). *Naturalista sicil.*, IV, 6: 429-434.
- Dall, W., B.J. Hill, P.C. Rothlisberg and D.J. Sharples. – 1990. The biology of the Penaeidae. In: Blaxter, J.H.S. and A.J. Southward (eds): *Advances in Marine Biology*. Academic Press, vol. 27: 489 pp.
- Demestre, M. – 1990. *Biología pesquera de la gamba Aristeus antennatus (Risso, 1816) en el mar Catalán*. Ph.D. thesis, Univ. Barcelona: 443 pp. +34 pl.
- Dietrich, B. – 1987. Review of the deep water shrimp stock and its exploitation in the waters off the People's Republic of Mozambique. *Fischerei-Forschung (Rostock)*, 3: 67-75.
- dos Santos, A.M. and A. Ribeiro Cascalho. – 1994. Present state of knowledge on *Aristeus antennatus* in the South of Portugal. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaeomorpha foliacea and Aristeus antennatus*. *N.T.R.-I.T.P.P. Special Publ.*, 3: 7.
- Draper, N. and H. Smith. – 1981. *Applied regression analysis*. Wiley & Sons: 709 pp.
- Ebert, T.A. and M.P. Russell. – 1994. Allometry and model II non-linear regression. *J. Theor. Biol.*, 168: 367-372.
- Farmer, A.S.D. – 1986. Morphometric relationships of commercially important species of penaeid shrimp from the Arabian Gulf. *Kuwait Bull. Marine Sci.*, 7: 121.
- Furnival, G.M. – 1961. An index for comparing equations used in constructing volume tables. *Forest Sci.*, 7: 337-341.
- Grey, D.L., W. Dall and A. Baher. – 1983. *A guide to the Australian Penaeid prawns*. Northern Territory Government: 140 pp.
- Hartnoll, R.G. – 1982. Growth. In: *The biology of Crustacea*. Academic Press, vol. 2: 111-196.
- Hartnoll, R.G. – 1985. Growth, sexual maturity and reproductive output. In: Wenner, A.M. (ed.): *Factors in adult growth*. Balkema: 101-128.
- Holthuis, L.B. – 1987. Crevettes. In: Fischer, W., M.L. Bauchot and M. Schneider (red.): *Fiches FAO d'identification des espèces pour les besoins de la pêche (Révision 1)*. Méditerranée et Mer Noire. FAO, Rome, vol. 1: 191-292.
- Jolicoeur, P. – 1975. Linear regressions in fishery research: some comments. *J. Fish. Res. Bd. Can.*, 32: 1491-1494.
- Leonart, J. – 1990. *La pesquería de Cataluña y Valencia: descripción global y planteamiento de las bases para su seguimiento. Informe final, tercer año*, CEE Dirección General XIV-B-1.

- Lovett, D.L. and D.L. Felder. – 1989. Application of regression techniques to studies of relative growth in crustaceans. *J. Crust. Biol.*, 9: 529-539.
- Martinez Baños, P. and J. Mas. – 1994. Life cycle of *Aristeus antennatus* in SouthEastern Spain. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaomorpha foliacea and Aristeus antennatus*. N.T.R.-I.T.P.P. Special Publ., 3: 9-10.
- Martinez Baños, P., F. Vizueté and J. Mas – 1988. Aspectos biológicos de la gamba roja *Aristeus antennatus* (Risso, 1816) a partir de las pesquerías del S.E. de la Península Ibérica. *Bentos*, 6: 235-243.
- Minervini, R., M. Bianchini, M. Giannotta, F. Lombardi, L. Morrési, V. Pollaci, E. Rambaldi and R. Sequi. – 1988. *Valutazione delle risorse demersali (gruppo tirrenico)*, U.O. 5 CoIPA: relazione triennale campagna pesca sperimentale 1985-1986-1987. Min. Marina Mercantile, Dir. Gen. Pesca Marittima (mimeo): 17 pp.
- Neter, J., W. Wasserman and M.H. Kutner. – 1985. *Applied linear statistical models*. R.D. Irwin: 11-27 pp.
- Pérez Farfante, I. – 1987. Revision of the gamba prawn genus *Pseudaristeus*, with description of two new species (Crustacea: Decapoda: Penaeoidea). *Fish. Bull.*, 85: 311-338.
- Pérez Farfante, I. – 1988. Illustrated key to Penaeoid shrimps of commerce in the Americas. NOAA, Technical Report NMFS n. 64: 32 pp.
- Ragonese, S. – 1995. Geographical distribution of *Aristaeomorpha foliacea* (Crustacea: Aristeidae) in the Sicilian Channel (Mediterranean Sea). *ICES Mar. Sci. Symp.*, 199: 183-188.
- Ragonese, S. and M.L. Bianchini. – 1995. Size at sexual maturity in red shrimp females, *Aristaeomorpha foliacea*, from the Sicilian Channel (Mediterranean Sea). *Crustaceana*, 68: 73-82.
- Ragonese, S., M.L. Bianchini and V.F. Gallucci. – 1994. Growth and mortality of the red shrimp *Aristaeomorpha foliacea* in the Sicilian Channel (Mediterranean Sea). *Crustaceana*, 67: 348-361.
- Relini Orsi, L. and G. Relini. – 1979. Pesca e riproduzione del gambero rosso *Aristeus antennatus* (Decapoda, Penaeidae) nel Mar Ligure. *Quad. Civ. Staz. Idrobiol. Milano*, 7: 39-62.
- Ribeiro Cascalho, A. and I. Arrobas. – 1982. *Aristeus antennatus* (Risso, 1816): some considerations about its biology and fishery in Portuguese waters. *ICES C.M.*, K/6: 23 pp.
- Ricker, W.E. – 1973. Linear regressions in fishery research. *J. Fish. Res. Bd. Can.*, 30: 409-434.
- Righini, P. and A. Abella. – 1994. Life cycle of *Aristeus antennatus* and *Aristaeomorpha foliacea* in the Northern Tyrrhenian Sea. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaomorpha foliacea and Aristeus antennatus*. N.T.R.-I.T.P.P. Special Publ., 3: 29-30.
- Sardà, F. – 1988. Progresos realizados en el conocimiento de la biología pesquera de la gamba *Aristeus antennatus* (Risso, 1816): ensayo de la evaluación de bancos en el Mediterráneo occidental. *FAO Rapp. Pêches*, 395: 76-83.
- Sardà, F. and J.E. Cartes. – 1994. Life cycle of *Aristeus antennatus* in the Catalan Sea. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaomorpha foliacea and Aristeus antennatus*. N.T.R.-I.T.P.P. Special Publ., 3: 21-22.
- Sardà, F. and M. Demestre. – 1987. Estudio biológico de la gamba *Aristeus antennatus* (Risso, 1816) en el Mar Catalán (NE de Espana). *Inv. Pesq.*, 51: 213-232.
- Sardà, F. and M. Demestre. – 1989. Shortening of the rostrum and rostral variability in *Aristeus antennatus* (Risso, 1816) (Decapoda: Aristeidae). *J. Crust. Biol.*, 9: 570-577.
- Sardà, F., C. Bas and J. Lleonart. – 1995. Functional morphometry of *Aristeus antennatus* (Risso, 1816) (Decapoda, Aristeidae). *Crustaceana*, 68: 461-471.
- Sokal, R.R. and F.G. Rohlf. – 1981. *Biometry*. W.H. Freeman & Co.: 843 pp.
- Somerton, D.A. – 1980. A computer technique for estimating the size of sexual maturity in crabs. *Can. J. Fish. Aquat. Sci.*, 37: 1488-1494.
- Spedicato, M.T., G. Lembo, P. Carbonara and T. Silecchia. – 1994. Biological parameters and dynamics of *Aristaeomorpha foliacea* in Southern Tyrrhenian Sea. In: Bianchini, M.L. and S. Ragonese (eds): *Life cycles and fisheries of the deep water shrimps Aristaomorpha foliacea and Aristeus antennatus*. N.T.R.-I.T.P.P. Special Publ., 3: 3536.
- Sprent, P. and G.R. Dolby. – 1980. The geometric mean functional relationship. *Biometrics*, 36: 547-550.
- Wilkinson, L. – 1987. *SYSTAT: the system for statistics*. SYSTAT Inc., Evanston IL.

Scient. ed.: J. Lleonart